Letters to the Editor.

[*The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, or to correspond with the writers of, rejected manuscripts intended for this or any other part of* NATURE. *No notice is taken of anonymous communications.*]

On the Continuous Radiation found in some Celestial Spectra beyond the Limit of the Balmer Series of Hydrogen.

IN the account of his observations of the eclipse of January 22, 1898, published in the Philosophical Transactions, A 197, pages 389 and 399, Mr. Evershed directed attention to a curious continuous spectrum emitted by the solar chromosphere and prominences. This spectrum begins near the limit or head of the Balmer series of hydrogen lines, and extends with gradually decreasing intensity in the direction of shorter wave-lengths. In describing the phenomenon Evershed referred to the early observation by Huggins of an absorption in the corresponding region in the spectra of Vega and other stars having especially strong hydrogen lines (stars of Class A),[1] and advanced the opinion that the spectrum, like the Balmer series which it so curiously supplements, is due to hydrogen. The grounds for this view were afterward strengthened through the discovery by Wood of a continuous spectrum occurring beyond the limit of the sodium series of dark lines, under conditions of laboratory experimentation that favoured the development of the higher members of the sodium series.[2] More recently an emission spectrum, apparently identical in character with the one observed by Evershed in the chromosphere, has been found to be characteristic of the planetary nebulæ.[3] The spectrum seems also to occur in the diffuse nebula N.G.C. 1499,[4] and has been a conspicuous feature in the radiation of the novæ. It may therefore be regarded as rather a commonplace phenomenon pertaining to the spectra of celestial objects which appear to exist under conditions of strong thermal or electrical excitation. For the purposes of this note I shall use the term *outlying spectrum* in referring to it in order to distinguish it from the general continuous spectrum of more uniform distribution which is found even in the gaseous or "bright-line" nebulæ.

The outlying spectrum, as an emission phenomenon, has not, that I am aware, been observed in the laboratory, except possibly by Dufour,[5] who found an ultra-violet continuous spectrum which, however, he associated with the *secondary* spectrum of hydrogen, and not with the Balmer series. In view of its general occurrence in a large group of extremely interesting and important celestial spectra, it would seem desirable that serious effort be directed toward its development in the laboratory, with the view of establishing the circumstances of its origin. As a preliminary step in estimating the conditions likely to prove favourable for its emission it may not be out of place to recall a theoretical explanation that has been advanced to account for it.

In a paper read two years ago before the American Philosophical Society,[6] the present writer suggested that the spectrum might be explained on the basis of the Bohr theory, as resulting from the capture of free electrons by hydrogen nuclei. Although the idea was developed from independent considerations, it cannot be regarded as an original one, since Bohr, in his first paper,[7] had suggested the reverse process to account for the sodium absorption referred to above as having been found by Wood. Inasmuch, however, as he had not applied the consideration to the explanation of an emission spectrum in that region (such as was known to exist in the spectrum of the chromosphere), it seemed appropriate at the time to direct attention to that aspect of the theory, and I venture to revert to it here, both on account of its theoretical interest, and because it may possibly prove suggestive of the conditions under which the spectrum should be sought in the laboratory.

Briefly outlined, the argument is as follows: The mechanism which Bohr sets up for the hydrogen atom is a positive nucleus surrounded by an infinite series of fixed orbits in which it is possible for an electron to revolve. A line of the Balmer series is formed when an electron "jumps" from one of the outer orbits to the second one, and the complete series of lines results from the totality of transfers or jumps from all of the outer orbits. The frequency of vibration is in each case proportional to the energy set free in the transfer from the outer to the second orbit, and the frequency at the head, or limit, therefore corresponds to the energy set free in the fall of an electron from rest at infinity. An electron with an additional velocity of its own will of course give up more energy in its capture than one starting from rest, so it will have to be manifested by a radiation of proportionately greater frequency, that is to say of less wave-length, than that of the series limit. The exact position of the resulting line will depend upon the amount of the initial kinetic energy, and since this must, in general, vary from one electron to another, the totality of these radiations should make up a continuous spectrum beginning at the Balmer limit and extending into the ultra-violet. It is thus seen that, by this theory, the Balmer series is caused by the falling inwards of electrons forming part of the atomic system, while the outlying spectrum is due to the capture of extraneous electrons. It is scarcely necessary to point out that the reasoning applies with equal force to the Ritz and Lyman series, and to other series of like character.

Preliminary to discussing this explanation it is well to calculate the initial kinetic energy required to produce the observed spectrum. The outlying spectrum can be followed in a number of planetary nebulæ to about 3340Å. This is of course an extremely rough estimate, for the spectrum is faint, and on this side fades gradually to invisibility. The energy required to develop a line here may conveniently be expressed in terms of that needed at the Balmer limit (3646Å) as

$$365/334 \times \nu_1 h = 365/334 \times Nh/4,$$

where ν_1 is the frequency at the Balmer limit, N the series constant, and h is Planck's element of action. Of this energy the amount $Nh/4$ has been developed in capture, leaving the remainder as the original kinetic energy of the electron. Calling this Ek, we have

$$Ek = 31/334 \times Nh/4,$$

substituting the numerical values: $h = 6{\cdot}547 \times 10^{-27}$ and $N = 3{\cdot}290 \times 10^{+15}$,

$$Ek = 5{\cdot}00 \times 10^{-13}. \quad . \quad . \quad . \quad . \quad (1)$$

This is the amount of kinetic energy which must have been possessed by the electron before coming under the action of the capturing nucleus in order that it should be able to develop a line at 3340A.

---

[1] "An Atlas of Representative Stellar Spectra," p. 85. For a more complete investigation of the absorption in the Class A stars, see Hartmann, *Physik. Zeit.*, 18, 429, 1917.

[2] *Astrophys. Jour.*, 29, 100, 1909.

[3] *Lick Obs. Bull.*, 9, 54, 1917; also *Publ. Lick Obs.*, 13, 256, 1918.

[4] Hubble, *Publ. Astron. Soc. Pacific*, 32, 155, 1920.

[5] *Ann. Chim. et Phys.*, (8), 9, 361, 1906.

[6] Proc., 49, 530, 1920.

[7] *Phil. Mag.*, 26, 17, 1913.

If we regard the speed of the electron as having been acquired through intermolecular reactions making for the equipartition of energy, the above quantity should be comparable with the energy of molecular agitation. For a temperature of 1000° Abs. the mean kinetic energy of a molecule is

$$E(1000) = 2{\cdot}06 \times 10^{-13}. \quad . \quad . \quad . \; (2)$$

Comparing (1) and (2) it is apparent that a gas temperature of about 2500° will be required if an electron of average energy is to develop a line at 3340A. That position, however, marks the extreme end of the spectrum, and radiation in the neighbourhood is therefore to be regarded as due to the capture of electrons of exceptionally high speed. According to Maxwell's law an appreciable proportion of the molecules have three or four times the mean energy, and it is therefore permissible to divide our 2500° by some such figure as that. It accordingly seems reasonable to assume that 1000° Abs. Cent., or even a less temperature, in the presence of the proper degree of ionisation, would suffice to produce the observed spectrum.[1] The temperature of the chromosphere is of course very much higher than that. With respect to the nebulæ, while we have no general knowledge of their thermal states, it will be recalled that Buisson, Fabry, and Bourget have estimated the temperature of the Orion Nebula to be of the order of 15,000° Cent.[2] In the light of such an estimate, the theoretical requirement of 1000° cannot be regarded as extravagant.

The foregoing considerations related to the suggestions that the electron acquires its speed through equipartition of molecular energy, according to the kinetic theory; that is to say, the spectrum has been regarded as a "temperature effect." It is of course quite conceivable that the electronic velocity might be acquired in some other way, for instance, through the action of an electric field, or photoelectrically, as has been suggested to me by Prof. Frederick A. Saunders in a personal letter. The presence in the Class A stars of absorption beyond the Balmer limit may be taken as evidence that photoelectric ionisation is going on in their atmospheres, and as most of the planetary nebulæ have nuclei that are powerful radiators of ultra-violet light, the suggestion is an attractive one. However, unlike the Class A stars, the nuclei show no perceptible falling off in strength near the head of the Balmer series. If absorption through photoelectric action takes place it is probably higher in the spectrum.

The above remarks refer very largely to the upper, or more refrangible limit of the outlying spectrum; of greater importance is the lower limit, since here contact is established with the line series. The spectrum fades gradually to invisibility at the upper extremity; at the lower the termination is, on the other hand, quite abrupt, and should, according to what has been said, lie at the theoretical limit of the Balmer series. As a matter of fact it has been found, I believe in every case, to be perceptibly to the redward of that point. We recall that this outlying continuous spectrum comes down to the junction from the more refrangible part of the spectrum, and the line series reaches up from the other or redward end. The series limit is at 3646Å, while the edge of the outlying spectrum in the chromosphere, according to Evershed, lies at 3668Å; that is to say, the outlying spectrum overlaps the series limit by about 22Å; more than that, it extends 7A beyond the highest series line observed by Evershed (3661A). In the radiation of the nebulæ the end of the outlying spectrum is difficult to measure, but it lies quite certainly to the redward of the Balmer limit. In N.G.C. 7009 it has been estimated to be at about 3650A, in other nebulæ it is at a greater wave-length. More marked is the discrepancy for the absorption spectrum in the Class A stars. Thus in the spectrum of α Cygni the absorption spectrum may be said to begin at 3710 ± A, and to reach full strength at 3660 ± Å,[3] while for Vega[4] the corresponding positions are 3800 ± Å and 3710 ± A. In the latter case we have then the beginning of absorption 150Å to the redward of the series limit, a disparity between theory and observation that might raise a doubt as to whether the absorption bears in reality any relationship to the Balmer series. A consideration of the influence of density will, however, show that an inequality of that order is to be expected.

It is probably significant that in the spectra of α Cygni and of Vega the last of the recorded series lines falls in each case in the neighbourhood of the point where the outlying absorption attains its full value. Thus for Vega the series is lost at 3687Å, and the estimated position of the attainment of full absorption is 3710 ± Å; for α Cygni the highest line is 3668Å, with full absorption estimated to begin at 3660 ± A. The estimates of the position at which full absorption begins are difficult to make, and the positions given are only roughly approximate, but it is quite evident that the series of dark lines which lie to the redward, and the continuous spectrum which extends in the other direction, merge one into the other, and that the second begins at the *actual* and not at the *theoretical* limit of the first.

The inference that the continuous spectrum should begin at the theoretical limit is based on the assumption that the atomic orbits extend to infinity. Bohr has pointed out that the size of the orbit system is necessarily limited by the density of the radiating gas, and has explained the absence of lines of a very high order as a consequence. Applying this consideration to the theory of the outlying spectrum it seems necessary to substitute for the "orbit at infinity" adopted in our former reasoning, the largest orbit in effective operation. Into the atomic system, as circumscribed by this orbit, electrons may be conceived to enter with speeds from zero upward. Now an entering electron of speed zero has less energy than one moving in the outer effective orbit—less by just the kinetic energy of orbital motion. In dropping into the second orbit therefore it sets free a smaller amount of energy, and consequently produces a line of lower frequency (or greater wavelength) than that of the series line which corresponds to the outer effective orbit. But the line formed by this electron must mark the more refrangible edge of the outlying continuous spectrum. We should, therefore, expect the continuous spectrum to begin somewhere on the less refrangible side of the highest visible member of the Balmer series. In other words, there should be an "overlapping" of the bright-line and continuous spectra such as is actually found. The margin of overlap should be proportional to the kinetic energy of the electron in the outer effective orbit, and on this assumption is expressible by the relation:

$$\nu_2 - \nu_3 = \nu_1 - \nu_2,^5 \quad . \quad . \quad . \quad . \; (3)$$

---

[1] A higher estimate of the required temperature was given in the earlier paper. I have not at hand the computations on which it was based, but it seems to have been affected by some numerical error, probably the use of N in place of N/4 for the coefficient of *h* in the equations preceding (1) of this paper.

[2] *Astrophys. Jour.*, 40, 258, 1914.

[3] *Lick Obs. Bull.*, 10, 103, Fig. 1.

[4] *Publ. Lick Obs.*, 13, 257, Fig. 2. The positions for both Vega and α Cygni are scaled from the intensity curves in the respective references. They are subject to great uncertainty. Compare stellar intensity curves by Hartmann, *Phys. Zeit.*, 18, 431.

[5] The expression follows at once from the frequency-energy relation assumed by Bohr. Let the *n*th be the largest effective orbit of one of his atomic systems; then for the highest line we have:

$$\nu_2 = N(1/2^2 - 1/n^2).$$

The second term in the parenthesis represents the energy lost during the

where ν_1 is the frequency at the theoretical limit of the Balmer series,
ν_2 is the frequency of the highest line that can be formed,
ν_3 is the frequency at the redward edge of the outlying spectrum.

This expression tells us that, expressed in frequencies (and the relation holds approximately for wave-lengths), the margin of overlap of the continuous and line spectra should be equal to the interval between the highest *observable* line of the Balmer series and the theoretical limit.

There are two factors tending to modify the above conclusion. One is that, by the kinetic theory, comparatively few electrons of approximately zero velocity are to be expected. Since these determine the redward edge of the outlying spectrum, that edge should be faint, and the effective limit might be of slightly less wave-length. The other is the fact that all the atomic systems will not at any one instant be reduced by molecular interference to outer orbits of exactly the same order. In these circumstances we should expect the large systems to determine the highest visible lines, and the small ones to establish the redward edge of the outlying continuous spectrum. The effect here would be to introduce a " blurring " factor, and increase the overlap. While these two factors operate against each other, it seems quite impracticable to attempt an estimate of their net effect.

To check the conclusions, the data on the emission spectrum of the chromosphere and the absorption spectra of α Cygni and Vega are collected in the accompanying table. Unfortunately the emission spectra of the nebulæ have not been measured accurately enough to establish their limits. In our theoretical discussion we have regarded the problem from the point of view of emission, and it is perhaps not entirely justifiable to check the conclusions through recourse to absorption spectra, for absorption and emission cannot, in such a case, be regarded as exactly complementary. It is necessary, however, to use the stellar spectra, since, with that of the chromosphere, they constitute the only radiations that have been sufficiently well observed.

Source.	Highest line of Balmer series. Observed.	Commencement of continuous spectrum.	
		Observed.	Computed.
Chromosphere (em.) .	3657*	3668	3668
α Cygni (abs.) . .	3668	3700 ±	3691
Vega (abs.) . . .	3687	3800 ±	3729

* The most refrangible line observed by Evershed was 3661Å. Mitchell, on the occasion of the 1905 eclipse (*Astrophys. Jour.*, 38, 431, 1913: also Publ. Leander McCormick Obs., 2, 49), photographed six additional lines, the highest being at 3656.8Å, the value adopted here. Evershed's plates were taken with a prism spectrograph and Mitchell's with a grating instrument of considerably greater power. The greater extent of the latter's spectrum is no doubt due to that fact.

The last column contains the positions of the lower edge of the outlying spectrum computed from the frequencies of the highest visible lines, using equation (3). The discrepancy between the observed and derived values for Vega is rather large and undoubtedly exceeds the error of measurement. It should be remembered, however, that in the atmosphere of a star absorption must take place throughout a considerable range of density, corresponding to different levels. The higher lines of the series, on which the computations rest, probably originate in the upper and rarer atmosphere, where the conditions are favourable for their formation, while we should expect the edge of the outlying spectrum to be determined in a region of comparatively high density. This would account for a divergence such as the one shown. Considering the number of extraneous factors that have a bearing on the problem the agreement is probably as good as might be expected. The measurements show the progress of the edge of the outlying spectrum toward the redward as the higher members of the Balmer series fade out, and this is in general accord with the theoretical deductions.

Summary of Conclusions.—The outlying continuous spectrum found in certain celestial spectra beyond the limit of the Balmer hydrogen series is, as was suggested by Evershed, almost certainly due to hydrogen. It should be more completely studied astronomically and serious effort should be directed toward developing it in the laboratory, on account of its theoretical interest and of its bearing on astronomical problems.

The spectrum is explicable, on the basis of the Bohr theory, as resulting from a change of state, as between a free electron and one in the second orbit. Bohr's original application of the principle to the case of absorption through photoelectric action on hydrogen atoms, is extended to the conception of emission as resulting from the capture of free electrons by hydrogen nuclei.

Theory and observation are in accord in placing the beginning of the outlying spectrum, not at the theoretical limit of the Balmer series, but to the redward of it, the amount of the displacement being greater as the number of observed series lines is less.

It seems possible to account for the spectrum on the basis of either thermal or electrical excitation. Regarded as a heat effect, it indicates for the planetary nebulæ a temperature of the order of 1000° Abs. Cent. or more. (The figure is not, however, offered as an estimate of the temperature of the nebulæ.)

W. H. WRIGHT.

Mount Hamilton, California, April 21, 1922.

Discoveries in Tropical Medicine.

I HAVE never thrown any doubt upon the influence of the suggestions made by Manson to Ross which led to the close study by Ross of the carriage of the malaria parasite (of both birds and man) by mosquitoes, and the discovery by him that mosquitoes of the kind known as Anopheles and not those of the kind known as Culex are the " intermediate hosts," in which the parasites causing malaria in man undergo necessary and remarkable stages of their development.

I was a member of the Committee of the Royal Society with which Ross was in constant communication during his work in India, and followed that work step by step in the reports sent home by him. My knowledge of the work of Laveran, of Labbé, Danilewski, and of Celli and of Grassi and the Italian school does not support the claims to "discovery" put forward on behalf of Manson by some of his friends. They are exaggerated and inaccurate—though Manson's influence and enthusiasm need no such mistaken advocacy in order to receive recognition.

It is the fact, in spite of assertions to the contrary, that Manson did *not* discover the part played by the mosquito in the transmission of *Filaria sanguinis hominis*. Important details as to the part played by the mosquito—of whatever kind—in that transmission have yet to be ascertained. They are still—at the present moment—a subject of investigation.

---

transfer from infinity to the *n*th orbit. This is also equal to the kinetic energy of the electron due to motion in its orbit, so that an electron at rest at the *n*th orbit will have lost twice that amount. Therefore

$$\nu_3 = N(1/2^2 - 2/n^2).$$

Remembering that $\nu_1 = N/2^2$, the relation (3) follows.